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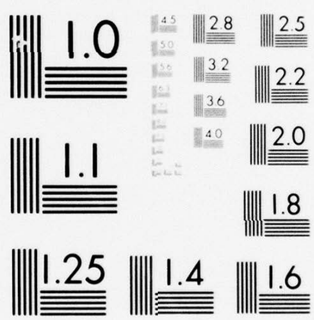
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MISCELLANEOUS PAPER H-77-5

PRESSURE TESTS IN FLOOD-CONTROL CONDUIT, MELVERN DAM, KANSAS

by

Timothy L. Fagerburg

Hydraulics Laboratory
U. S. Army Engineer Waterways Experiment Station
P. O. Box 631, Vicksburg, Miss. 39180

May 1977
Final Report

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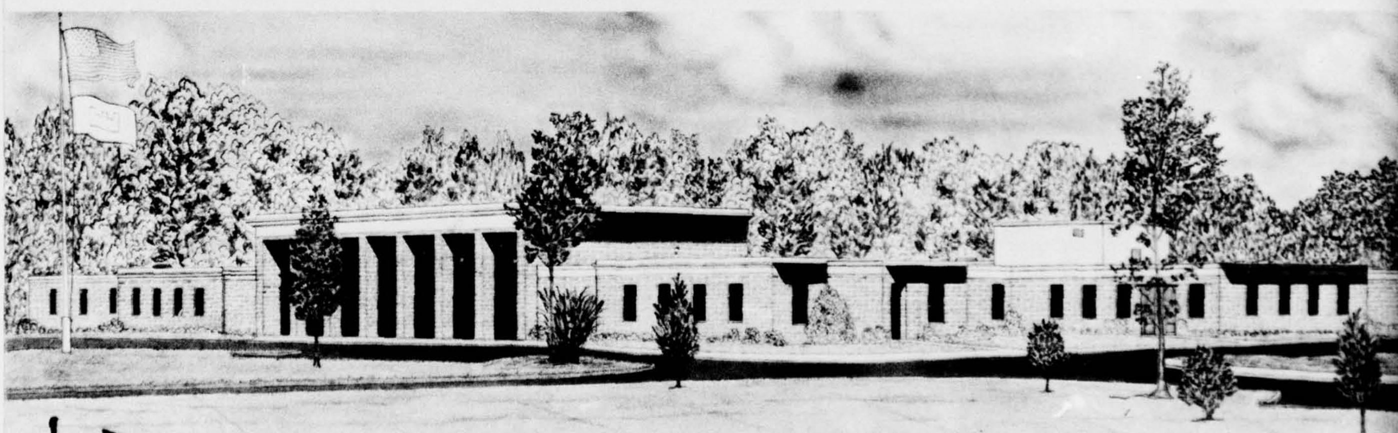

Prepared for U. S. Army Engineer District, Kansas City
Kansas City, Mo. 64106 and
Office, Chief of Engineers, U. S. Army
Washington, D. C. 20314

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Flood control	Prototype tests
Melvern Dam	

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Prototype tests were conducted at Melvern Dam, Kansas, to determine pressures on the flood-control conduit walls and to obtain the hydraulic (piezometric) grade lines of the system. No critical pressures were observed during the operation of the tests. Resistance coefficients and intake losses were also obtained. The findings were comparable to those obtained from tests at similar projects.

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PREFACE

The prototype tests described in this report were conducted in June 1976 by personnel of the Hydraulics Laboratory (HL), U. S. Army Engineer Waterways Experiment Station (WES), for the U. S. Army Engineer District, Kansas City, and Office, Chief of Engineers, U. S. Army.

Acknowledgment is made to the individuals of the Kansas City District who contributed substantially to the completion of these tests. Mr. T. L. Fagerburg, hydraulic engineer, Prototype Branch, HL, was WES Project Engineer. This report was prepared by Mr. Fagerburg under the supervision of Mr. E. D. Hart, Chief, Prototype Branch, Mr. E. B. Pickett, Chief, Hydraulic Analysis Division, and Mr. H. B. Simmons, Chief, HL, all of WES. Appendix A was prepared by Mr. Hart.

COL J. L. Cannon, CE, was Commander and Director of WES during the study and the preparation of this report. Mr. F. R. Brown was Technical Director.

CONTENTS

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
inches	25.4	millimetres
feet	0.3048	metres
miles (U. S. statute)	1.609344	kilometres
acre-feet	1233.482	cubic metres
cubic feet per second	0.02831685	cubic metres per second
pounds (force) per square inch	6894.757	pascals
inches per second	2.54	centimetres per second
feet per second	0.3048	metres per second
feet per second squared	0.3048	metres per second squared
square feet per second	0.0929	square metres per second
Fahrenheit degrees	0.555	Celsius degrees or Kelvins*

* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: $C = (5/9)(F - 32)$. To obtain Kelvin (K) readings, use: $K = (5/9)(F - 32) + 273.15$.

PRESSURE TESTS IN FLOOD-CONTROL CONDUIT
MELVERN DAM, KANSAS

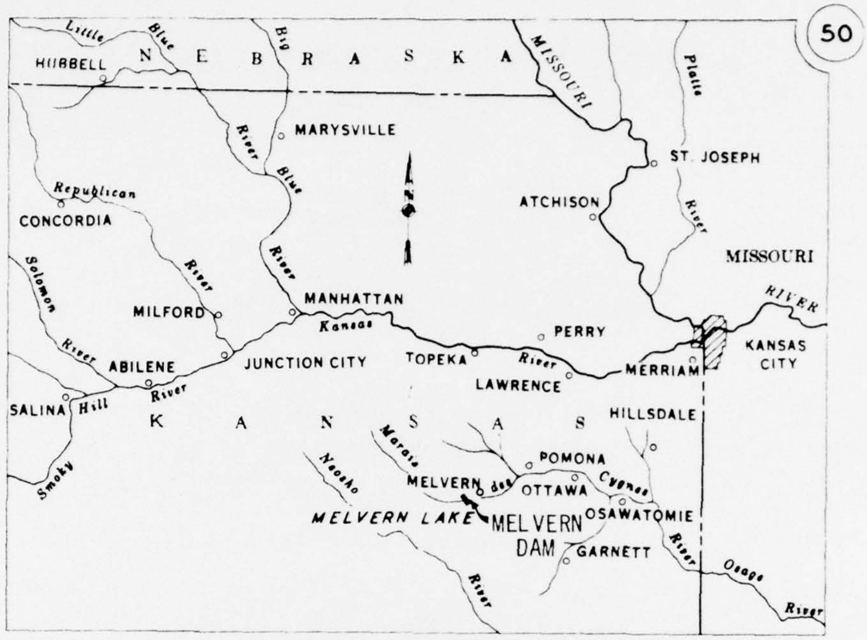
PART I: INTRODUCTION

Pertinent Features of the Project

1. Melvern Dam (Figure 1) is on the Marais des Cygnes River in Osage County, Kansas, about 72 miles* southwest of Kansas City (Figure 2). The dam is a rolled earth-fill structure, 9700 ft long, that extends 125 ft above the streambed. The total storage capacity of the reservoir

Figure 1. Melvern Dam, Kansas

* A table of factors for converting U. S. customary units of measurement to metric units can be found on page 4.



LOCATION

Figure 2. Vicinity map

is 363,000 acre-ft when filled to spillway crest el 1057.0.*

Outlet Works

2. Flood-control releases are controlled by a gated intake tower containing two 6.0- by 12.0-ft, hydraulically operated, vertical slide gates (Figure 3). Low-flow releases are controlled by two 2.33- by 2.17-ft vertical slide gates, one located within each of the larger flood-control gates.

3. The flood-control and low-flow intakes discharge into a 40-ft-long transition section and then into a single 11.5-ft-diam horseshoe conduit. The flow then passes through an 822-ft-long conduit before

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* All elevations (el) cited herein are in feet above mean sea level (msl).

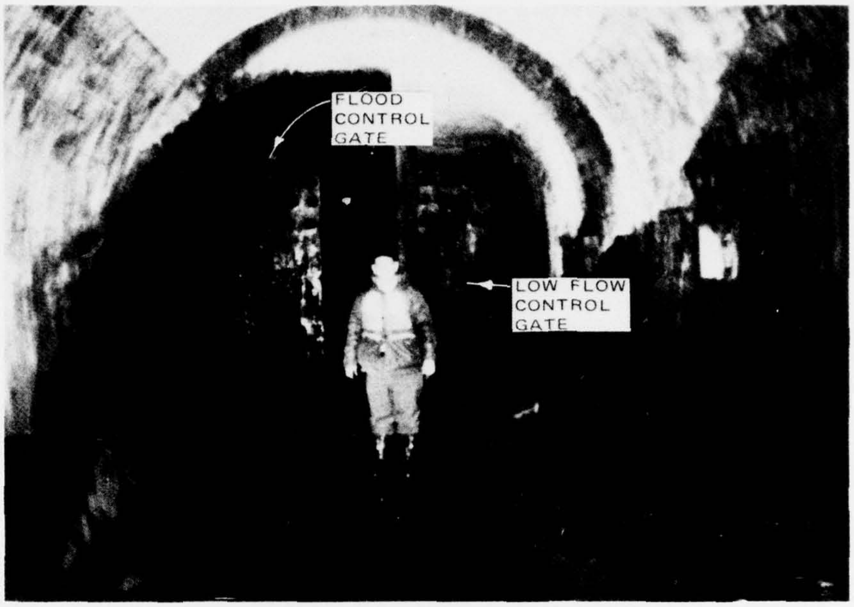

Figure 3. Flood-control vertical slide gates

discharging into a conventional hydraulic-jump-type stilling basin (see Plate 1).

Purpose and Scope of Tests

Purpose

4. The principal objectives of the tests conducted in this study were to obtain prototype data on flood-control conduit wall pressure fluctuations and to define the hydraulic (piezometric) grade lines of the system. The prototype data would then be correlated with other similar data to develop improved design criteria.

Scope

5. Because of downstream channel conditions, flood-control releases were limited; e.g., with two gates fully open (full conduit flow conditions), the time of testing was restricted to 1 hr from the time the required gate opening was obtained to the start of gate closing. This was followed by a 3-hr period of no flow to allow downstream

water elevations to subside. Measurements in the conduit during flood-control release consisted of:

a. Pressures along the conduit wall to determine the piezometric grade lines. This information was used in evaluating resistance and intake losses, the water surface profiles of partial gate opening flows, and the elevation of the hydraulic grade line at the outlet.

b. Pressure fluctuations on the conduit wall due to flow expansion within the transition section and downstream of the transition section.

PART II: TEST FACILITIES, EQUIPMENT, AND PROCEDURES

Testing Facilities

6. During construction of the project, 12 piezometer pairs were installed along the sides of the conduit at the spring line (Plate 1). Each piezometer pair consisted of 1/4-in.-diam orifices on opposite sides of the conduit. The leads from the orifices terminate in a manifold (Figure 4) located in a manhole (manometer well) near the conduit outlet.

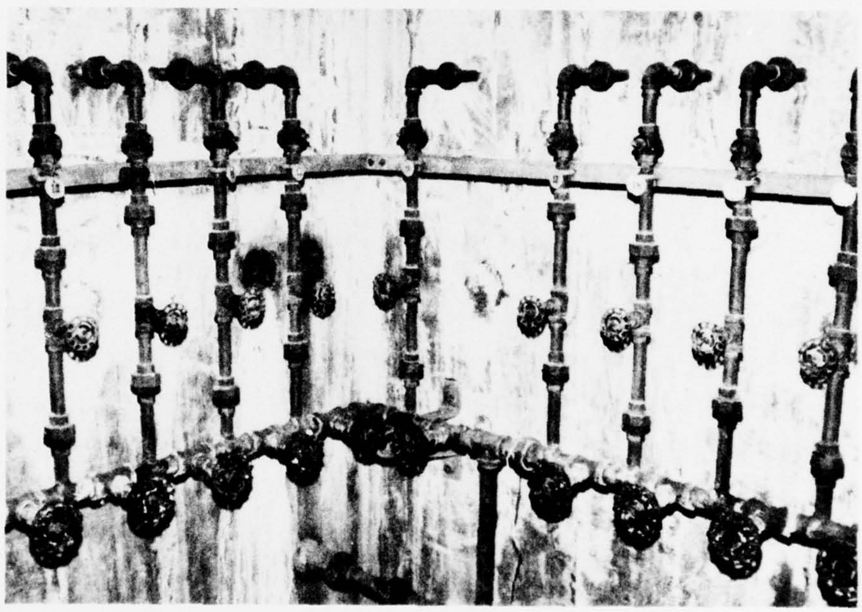

Figure 4. Piezometer manifold system

7. A transparent plastic tube was connected to the piezometer manifold and extended up a staff gage on the wall of the manometer well. The piezometer head was read directly by measuring the elevation of the water in the tube (Figure 5). During operations, the valves to two piezometers (one pair) were opened simultaneously and the measured piezometeric head was taken as an average.

8. Five pressure transducer mounting boxes with removable cover plates were installed in the conduit walls during construction. The

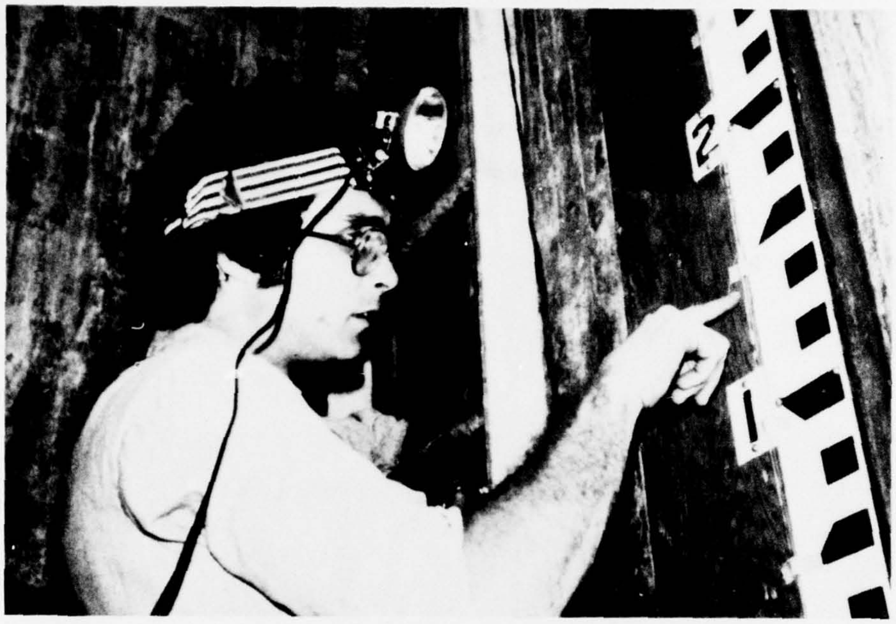

Figure 5. Piezometric head measurements at manometer well with vertical plastic tube and staff gage

locations of these pressure transducers, designated T1-T5, are shown in Plate 1. A duplicate set of cover plates was sent to the U. S. Army Engineer Waterways Experiment Station (WES) where they were drilled and tapped for the pressure transducer adapters. The transducers were calibrated in the field (prior to beginning the tests) as a final check on the laboratory calibrations. The calibration method is described in Appendix A.

9. The electrical cable from each of the five pressure transducers was threaded through a protective conduit that terminated in the gated intake tower recording area at el 987. The signals from the transducers were amplified and then recorded by an oscillograph (Figure 6) at chart speeds from 0.4 to 10.0 ips.

Other Instrumentation

10. The discharge measurements, conducted by local U. S. Geological Survey personnel, were made at a bridge 3/4 mile downstream of the

dam (see Figure 1). The instrument used for measurement was a Price AA Current Meter.

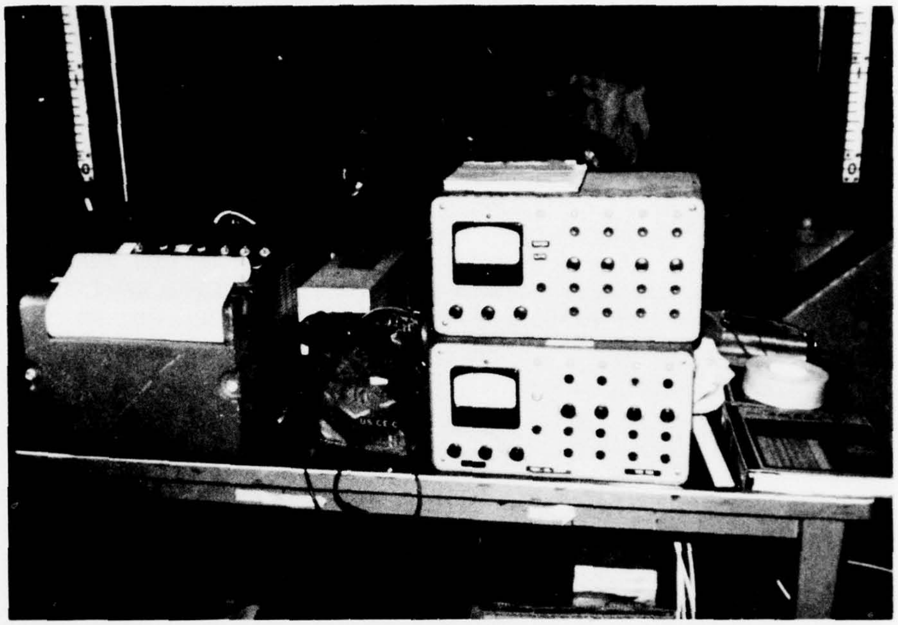

Figure 6. Recording equipment

Test Procedures

11. Four tests were conducted at Melvern Dam for flood-control system measurements. For these measurements, the control gates were varied in number open and percentage of opening. Due to the previously discussed time element involved in allowing the downstream water surface elevation to recede, only two tests per day could be made. The test conditions were:

Test No.	Gate Openings,* ft Left	Gate Openings,* ft Right	Discharge cfs	Pool Elevation	Water Temperature, °F	Jun 76 Date
1	12.0	12.0	5570	1036.55	75	29
2	0.0	12.0	2910	1036.34	75	29
3	9.5	9.5	5250	1036.34	75	30
4	12.0	0.0	2960	1036.18	75	30

* Looking downstream.

12. The test program consisted of static calibrations followed by the test runs under specified conditions. The test procedures were as follows:

a. Gate settings were made.

b. All piezometer systems were bled.

c. All participating personnel were alerted.

d. Recorders were turned on to warm up.

e. After all piezometer readings were taken, the last portion of the test was recorded on the oscillograph charts at speeds from 0.4 to 4.0 ips and from 1.0 to 10.0 ips. Information pertinent to each test was marked on the oscillogram.

Test Data

13. The data consisted of:

a. Piezometric head readings for the 12 piezometer pairs.

b. Temperature, discharge, and reservoir pool elevations for all four tests.

c. Nine 2-in.-square plaster casts of the conduit wall.

d. Oscillograms of the pressure transducer readings.

PART III: TEST RESULTS

Conduit Pressures

14. Pressures were measured along the conduit wall during the flood-control tests to obtain the hydraulic grade lines. The hydraulic grade lines, determined by the least squares method, are plotted in Plate 2 for pressure flow tests 1 and 3 and the data for all tests are listed below.

Piezometer			Piezometer Pressure Elevations for Flood-Control Tests			
Pair	Station*	Elevation	1	2	3	4
1, 2	2+55U	966.58	982.85	966.40	980.60	966.80
3, 4	2+05U	965.95	980.95	966.65	979.00	966.50
5, 6	1+55U	965.32	978.20	965.30	976.95	964.90
7, 8	1+05U	964.69	976.85	965.40	975.15	965.15
9,10	0+55U	964.06	975.15	964.90	973.80	964.45
11,12	0+45D	962.80	970.85	963.35	969.95	963.40
13,14	1+45D	961.54	967.85	962.80	967.00	962.90
15,16	1+95D	960.90	965.50	961.85	965.25	961.90
17,18	2+45D	960.27	964.40	961.70	963.90	961.70
19,20	2+95D	959.64	961.70	960.65	961.50	960.60
21,22	3+45D	959.01	960.25	960.00	960.15	960.05
23,24	3+95D	958.38	958.15	959.05	958.48	959.00
Pool Elevation			1036.55	1036.36	1036.34	1036.18
Average discharge Q, cfs			5570	2910**	5250	2960**
Average $\overline{V}$, ft/sec			50.82		47.90	
Darcy-Weisbach resistance coefficient[1]			0.01069		0.01093	
Reynolds Number			5.94×10^{-7}		5.60×10^{-7}	

* U = upstream of axis of dam; D = downstream of axis of dam.
** Open-channel flow.

Resistance and intake loss coefficients were determined from the hydraulic grade lines of tests 1 and 3. Tests 2 and 4, as stated previously, were single-gate operations in which full conduit flow did not occur. As a result, the hydraulic grade lines actually represent the water surface elevations and are given in Plate 2.

Resistance Loss Coefficients

15. The resistance loss coefficients f were determined using the Darcy-Weisbach resistance coefficient equation. This equation is defined as:[1]

$$f = \frac{H_f}{\left(\frac{L}{D}\right)\frac{\overline{V}^2}{2g}} \tag{1}$$

where

H_f = head loss due to normal boundary friction, ft

L = length of conduit over which the head loss is determined, ft

D = equivalent hydraulic diameter; 4(cross-sectional area/wetted perimeter), ft

$\overline{V}$ = average velocity in conduit, ft/sec

g = acceleration of gravity, ft/sec^2

16. The resistance coefficients for tests 1 and 3 were computed using the resistance head loss from the lower end of the conduit transition section to the outlet (Plate 1). As a result of the test operating conditions (see tabulation, paragraph 11), tests 2 and 4 exhibited open-channel flow; therefore, the resistance loss coefficients were not computed. The Reynolds numbers R_e for pressure flow in tests 1 and 3 were computed using:

$$R_e = \frac{\overline{V}D}{\nu} \tag{2}$$

where ν = kinematic viscosity, ft^2/sec. The resistance coefficients and Reynolds numbers for tests 1 and 3 are given in the tabulation in paragraph 14. Plate 3 is a plot of resistance factors versus Reynolds number and wall roughness.

Plaster Casts

17. Nine 2-in.-square plaster casts of the conduit wall surface were made prior to the flood-control pressure tests. A typical surface profile was obtained by traversing the surface of the plaster casts with a sharp probe on an Ames dial gage (Figure 7). The mean gage reading

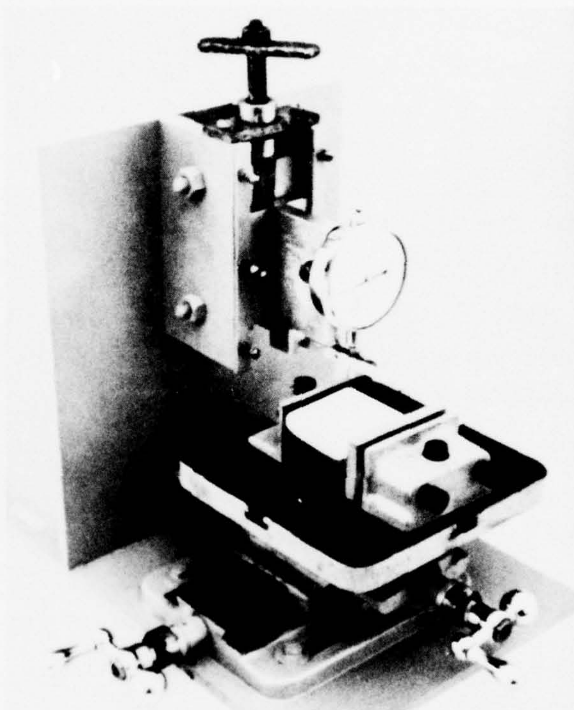

Figure 7. Surface roughness profiler

was computed by the method of least squares.[2] The standard deviation from the mean gage reading σ was taken as one half of the absolute roughness[3] ($\varepsilon/2$). The relative roughness ε/D was then computed. The average relative roughness and equivalent resistance coefficients of the conduit are presented below.

Cast No.	Station	σ, ft	ε, ft = 2σ	ε/D	f
2	3+95D	0.00026	0.00052	0.000045	0.0103
3	3+45D	0.00022	0.00043	0.000038	0.0100

(Continued)

Cast No.	Station	σ, ft	ε, ft = 2σ	ε/D	f
4	2+45D	0.00031	0.00062	0.000059	0.0107
5	2+45D	0.00029	0.00059	0.000052	0.0106
6	0+45D	0.00110	0.00230	0.000200	0.0137
7	0+45D	0.00039	0.00077	0.000067	0.0111
8	1+05U	0.00036	0.00072	0.000063	0.0109
9	1+05U	0.00063	0.00120	0.000110	0.0122
10	2+05U	0.00046	0.00091	0.000079	0.0115
			Average =	0.000079	0.0112

Intake Losses

18. The intake loss is defined in HDC 221-1[4] as the total available head minus the velocity head and resistance loss in the conduit. The intake loss coefficient K_e includes all losses through the intake section, but excludes the gate loss for partial gate openings. Tests 1, 2, and 4 were for full gate openings and test 3 was for a partial gate opening. However, as stated previously, only tests 1 and 3 were full conduit flow runs.

19. The total losses of the intake section were obtained from the difference in the pool elevation and the total energy grade line elevation at the lower end of the conduit transition section (sta 3+17U). The intake loss coefficients obtained are given below.

Test No.	K_t*	K_g**	K_e†	Comments
1	0.28	0	0.28	2-gate operation, full gate opening
3	0.50	0.22	0.28	2-gate operation, partial gate opening
				Coefficients in both are computed on the basis of the velocity in the conduit proper

* Total intake loss coefficient = (total available head - velocity head)/velocity head.

** Partial gate opening loss coefficient.

† Intake loss coefficient = $K_t - K_g$.

The intake loss coefficient obtained in this manner (0.28) for two-gate operation compares favorably with the value (0.25) obtained for two-gate

operation of Fort Randall.[1] The additional loss due to partial gate opening was estimated using the operating conditions governing tests 1 and 3 and assuming that the values of K_e would be the same for both tests. The K_g value for test 3 was then found to be the difference between the K_t and K_e values for test 3.

Conduit Wall Pressures

20. Pressures were measured at transducers T1-T5 to determine the average wall pressure and fluctuations. Plate 4 is a sample of the oscillograms obtained from test 3. The most significant average pressures and fluctuations are presented below:

Test No.	Gate* Opening ft	Transducer No.	Sta**	El	Avg Pressure ft	Peak-to-Peak Pressure ft	Peak-to-Peak Relative to $V^2/2g$	Comments
1	B 12.0	T1	3+48U	968.0	24.36	2.43	0.061	Q = 5570 cfs
		T2	3+06U	967.2	14.64	5.48	0.137	
		T3	2+96U	967.1	20.57	4.50	0.112	
		T4	2+86U	966.9	19.14	5.18	0.129	
		T5	2+76U	966.8	19.87	8.55	0.213	
2	R 12.0	T1		968.0	-1.51	--	--	Q = 2910 cfs
		T2		967.2	-1.22	--	--	
		T3		967.1	-0.86	--	--	
		T4		966.9	-0.81	--	--	
		T5		966.8	2.60	5.78	--	
3	B 9.5	T1		968.0	10.73	8.19	0.230	Q = 5250 cfs
		T2		967.2	10.71	7.89	0.221	
		T3		967.1	15.64	7.29	0.205	
		T4		966.9	14.98	6.47	0.182	
		T5		966.8	14.02	6.63	0.186	
4	L 12.0	T1		968.0	34.42	3.58	--	Q = 2960 cfs
		T2		967.2	-6.70	3.35	--	
		T3		967.1	3.53	3.47	--	
		T4		966.9	3.47	3.18	--	
		T5		966.8	1.45	3.12	--	

Note: Dashes denote recorded data insignificant.
* R = right flood-control gate; L = left flood-control gate (looking downstream); B = both flood-control gates.
** U = upstream axis of dam.

Exit Portal Pressures

21. The elevations of the hydraulic grade lines at the exit portal at Melvern Dam were determined by extrapolating the fully developed piezometric grade lines to the exit. The pressures at the exit portal

were somewhat less than those observed at other dams (see HDC 225-1),[4] possibly due to the broader base of the horseshoe-shaped conduit.

PART IV: CONCLUSIONS

22. The conclusions resulting from analyses of these prototype tests are:

a. No critical pressures or pressure fluctuations were observed on the conduit wall during the normal operation of the dam.

b. Intake and conduit resistance loss coefficients are comparable to those computed from tests of similar dams.

c. The tests of single-gate operation indicate that full conduit flow cannot be obtained.

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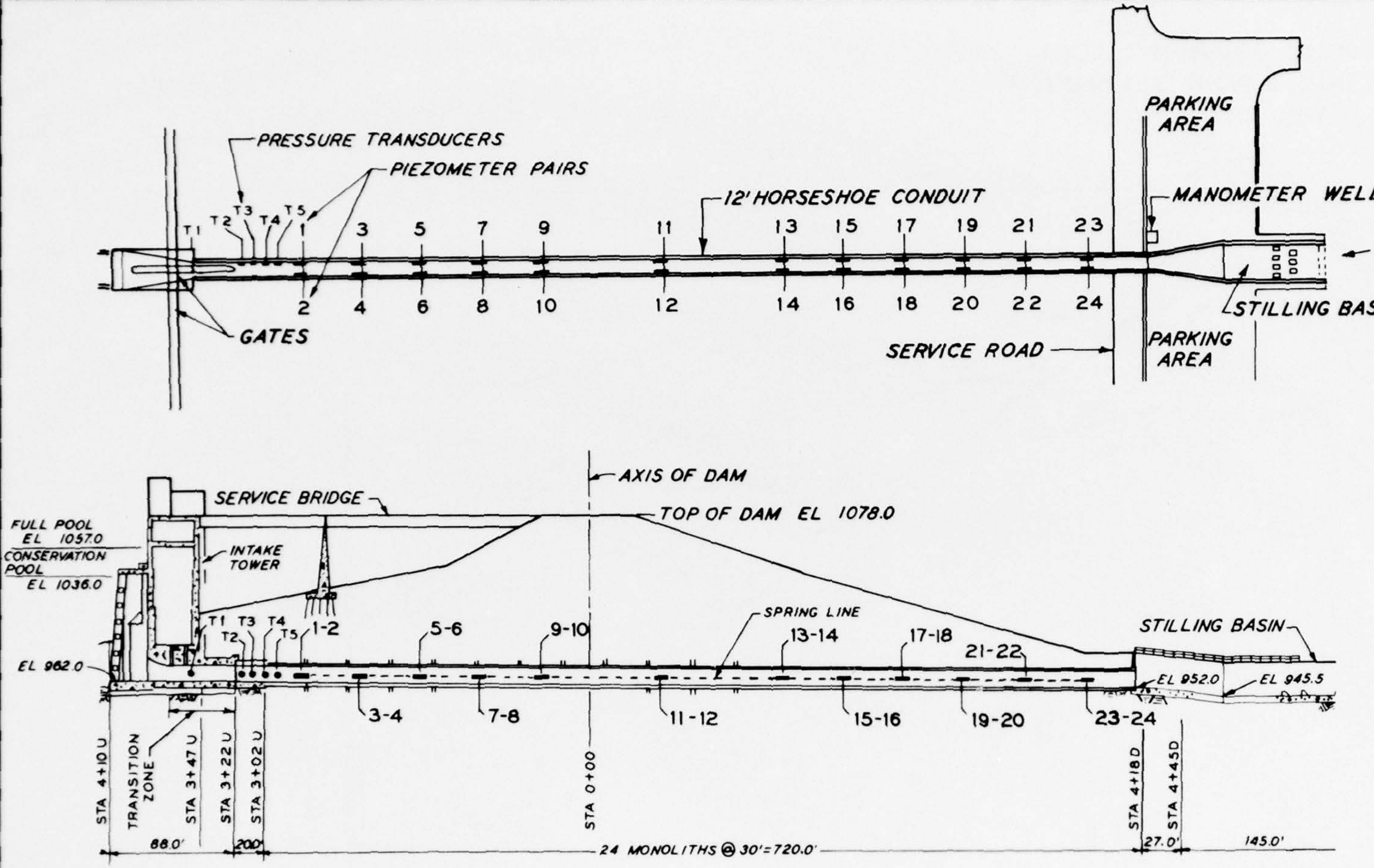
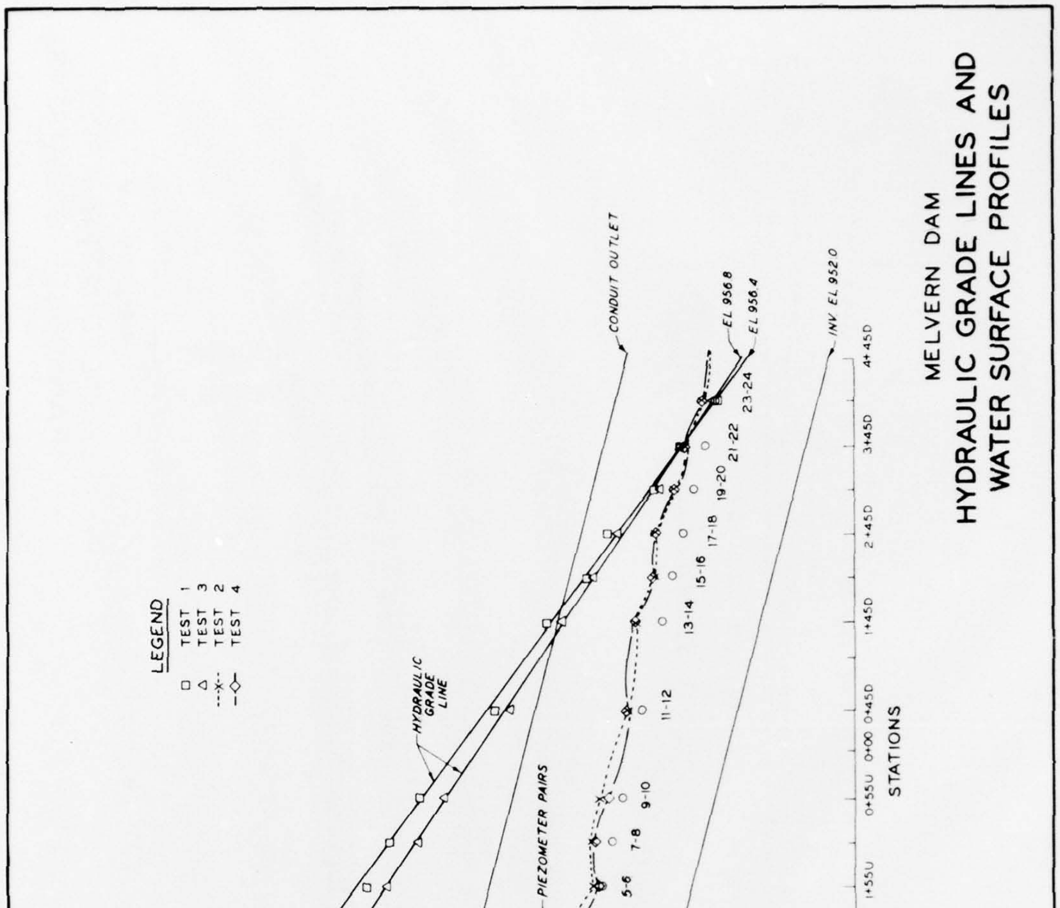


MELVERN DAM

PIEZOMETER AND TRANSDUCER LOCATIONS

PLATE 1


MELVERN DAM
HYDRAULIC GRADE LINES AND
WATER SURFACE PROFILES
LEGEND
TEST 1
TEST 3
TEST 2
TEST 4
HYDRAULIC GRADE LINE
PIEZOMETER PAIRS
PRESSURE TRANSDUCERS
T1
T2
T3
T4
T5
CONDUIT OUTLET
EL 956.8
EL 956.4
INV EL 952.0
EL 984.8
EL 982.6
STA 3+17U
STA 2+76U
INTAKE TOWER
CONSERVATION POOL EL 1036.0
ELEVATION, FT (MSL)
990
980
970
960
1-2
3-4
5-6
7-8
9-10
11-12
13-14
15-16
17-18
19-20
21-22
23-24
3+55U
2+55U
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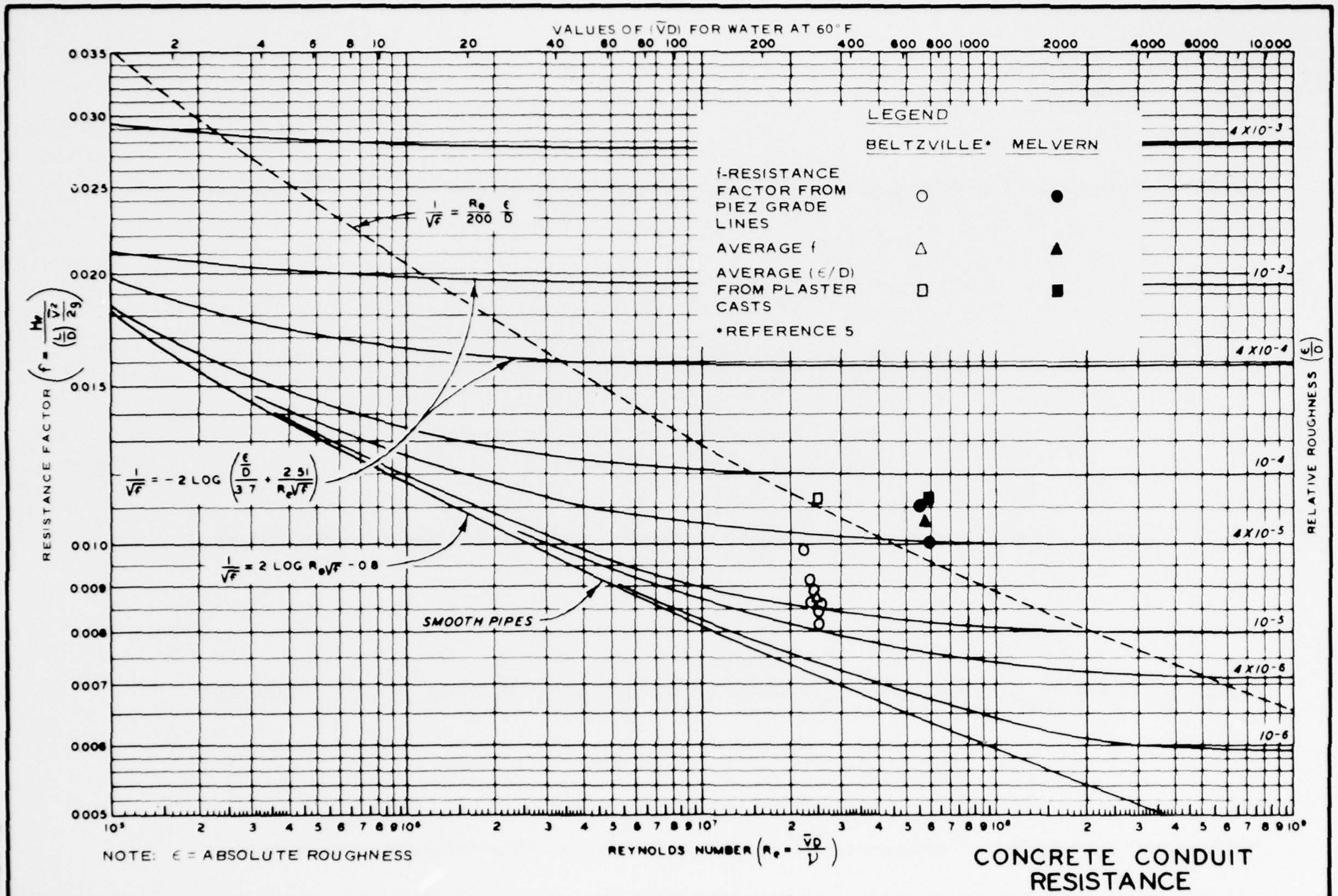
STATIONS

PLATE 2



CONCRETE CONDUIT RESISTANCE

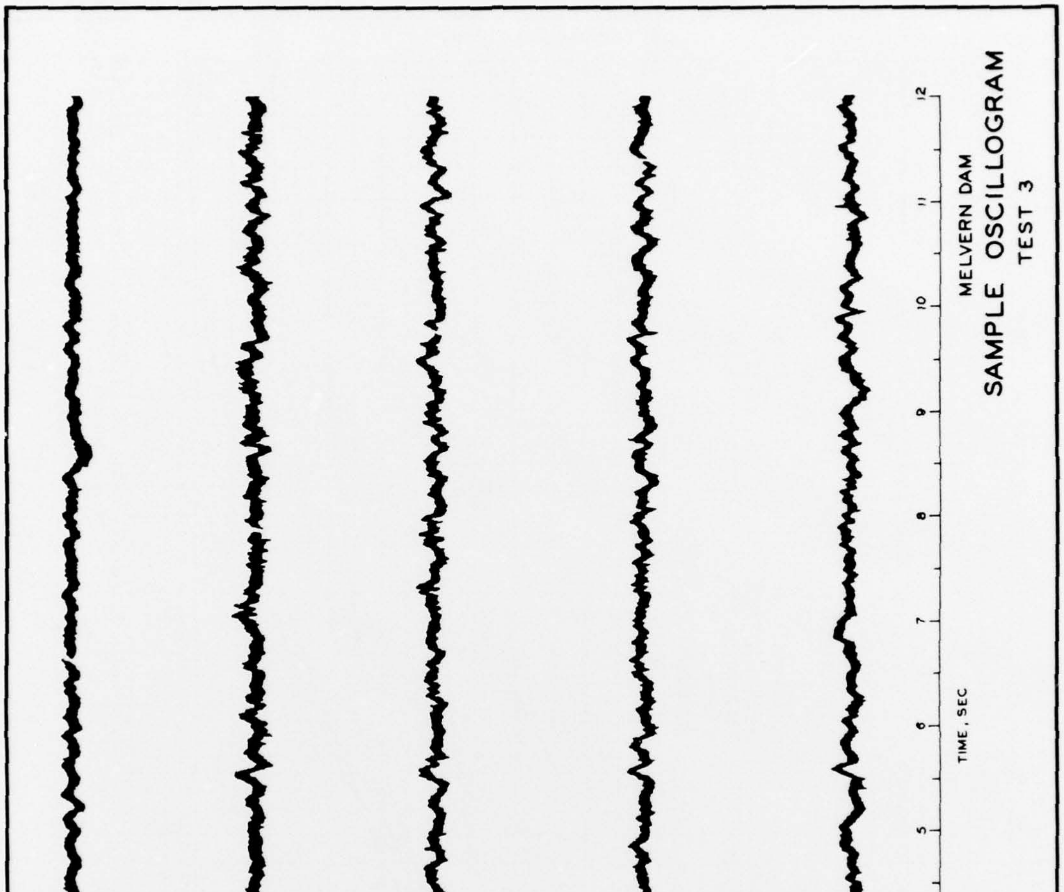

MELVERN DAM
SAMPLE OSCILLOGRAM
TEST 3
T1
T2
T3
T4
T5
WATER, FT
20
0
TIME, SEC
0
1
2
3
4
5
6
7
8
9
10
11
12
NOTE GATES OPEN 9.5 FT
Q = 5250 CFS

PLATE 4

APPENDIX A: FIELD CALIBRATION OF PRESSURE TRANSDUCERS

1. Pressure transducers (as well as other instrumentation) used in prototype tests such as those discussed in this report are calibrated in the laboratory before and after the tests. It is desirable to conduct a check on the calibrations in the field just prior to initiating the tests. Immediate results can then be observed with more confidence.

2. Field calibration checks are made where conditions permit. For example, during lock tests, pressures can be checked against known water-level elevations in the lock chamber. In conduits with downstream control gates (rare), checks can also be made on transducers installed in the conduit wall. As another example, for dissolved oxygen measurements, titrations of samples from the same point can be made to check electronic readings.

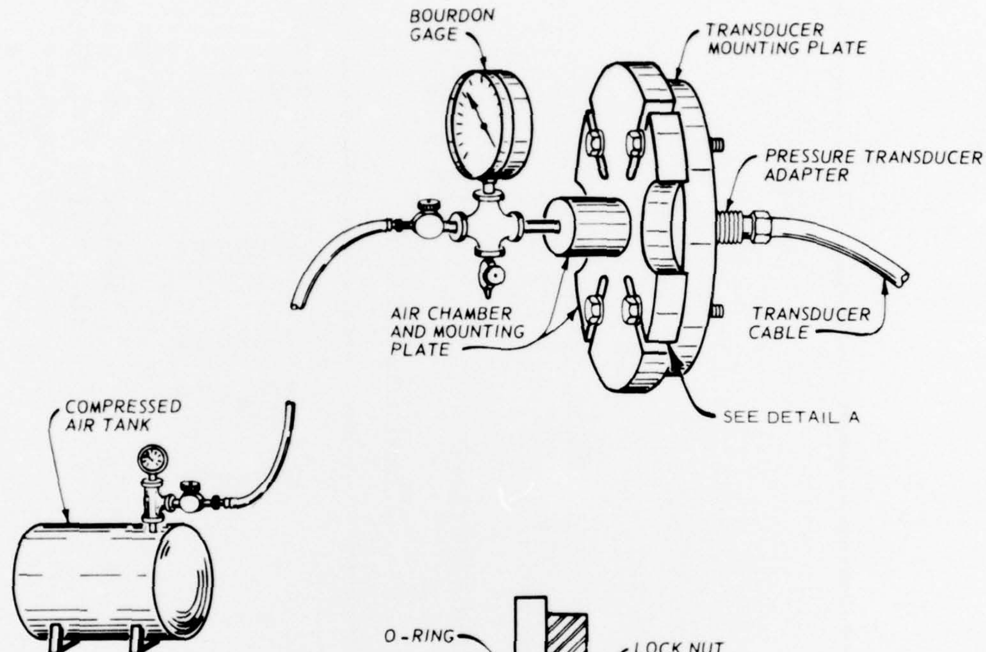
3. In many cases, field pressure calibrations cannot be made because access to a known pressure is not available. The Hydraulics Laboratory of the U. S. Army Engineer Waterways Experiment Station has devised a system that can be used for this purpose in many cases, as during the Melvern Dam prototype tests (Figure A1).

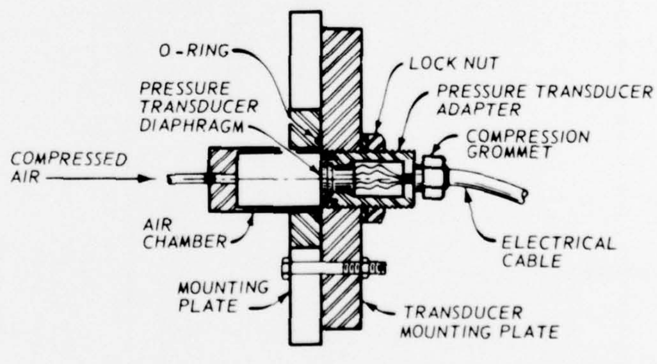
Figure A1. Field calibration check of pressure transducer

4. The method consists of applying compressed air to the pressure transducer diaphragm. The applied pressure is read from a well-calibrated Bourdon gage (or manometer as shown

in Plate A1. At this point, the pressure transducer, in its adapter, has been installed in the mounting plate and the cable has been run through the connecting conduit to the recording station. The mounting plate has not yet been installed flush with the conduit wall. Then, the field calibration mounting plate can be bolted flush with the transducer plate and air pressure applied from a compressor. At this time, the galvanometer shift caused by this pressure is recorded on the oscillograph chart (Plate A2). The displacement versus pressure relationship can then be determined and compared with the laboratory calibration.

5. Such a comparison is presented in Plate A2 for pressure transducer T3 of Melvern Dam prototype test 4. For comparable displacements (step C), the calibrations are within 3 percent and are thus considered close enough to conduct the test without adjustments.

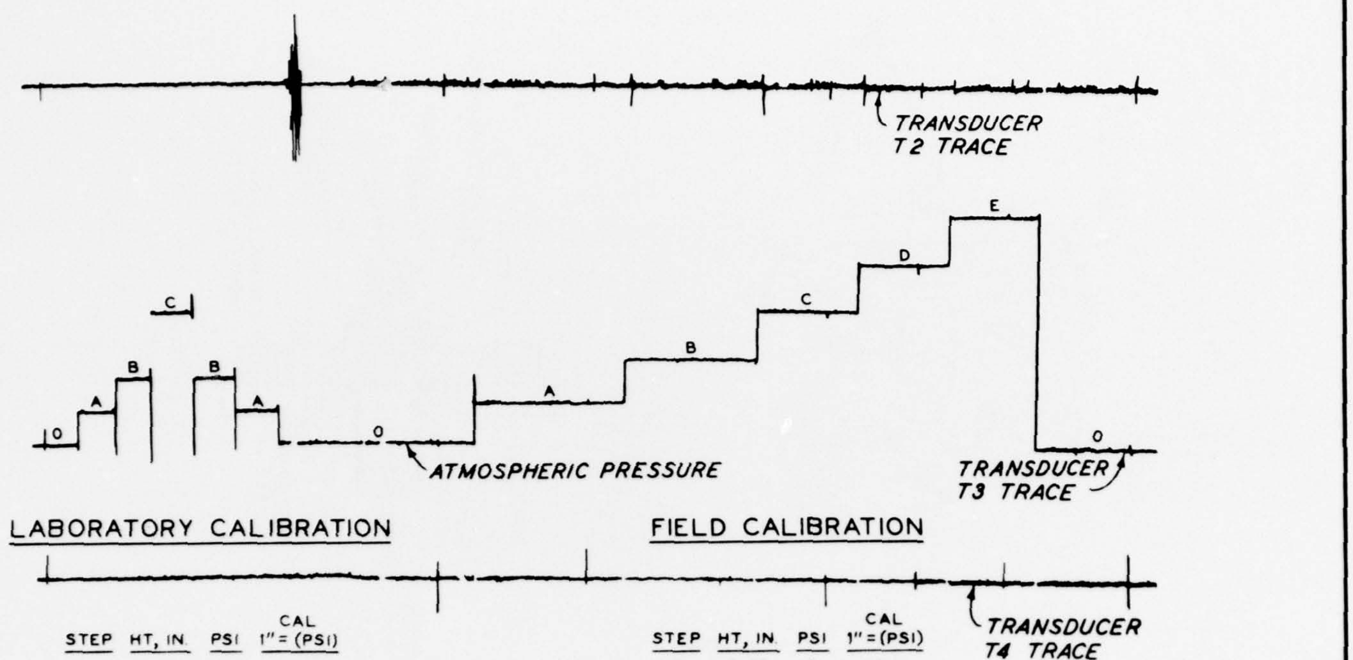




DETAIL A

MELVERN DAM

SYSTEM FOR FIELD CALIBRATION OF PRESSURE TRANSDUCERS



LABORATORY CALIBRATION

STEP	HT, IN.	PSI	CAL 1" = (PSI)
A	0.35	3.8	10.29
B	0.72	7.2	10.00
C	1.48	14.2	9.59

FIELD CALIBRATION

STEP	HT, IN.	PSI	CAL 1" = (PSI)
A	0.45	5	11.11
B	0.95	10	10.53
C	1.51	15	9.93
D	2.04	20	9.80
E	2.80	25	9.82

MELVERN DAM

COMPARISON OF LABORATORY AND FIELD CALIBRATIONS OF TRANSDUCER T3

TEST 4

In accordance with ER 70-2-3, paragraph 6c(1)(b), dated 15 February 1973, a facsimile catalog card in Library of Congress format is reproduced below.

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